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Climate change vulnerability assessment for the uranium supply chain in Australia

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ABSTRACT

Uranium demand is expected to increase due to the worldwide growth in electricity demand and the shift towards more sustainable and reliable low carbon energy sources. For more than 10 years, the Australian uranium industry production (primarily represented by production from the Ranger and Olympic Dam Mines) has been affected by adverse weather conditions. Since Australia meets 12% of the current world uranium demand, there is a need to study, at depth, any potential threat to this market. This study has included a vulnerability assessment of the impact that climate change currently makes, and potentially might have on the supply chain of the two biggest uranium mines currently operating in Australia. The assessment identified the most vulnerable parts (past and future) of both operational chains, in addition to the chain participants with the greatest and least adaptive capacity.

1. Introduction

The energy sector has been classified as the greatest worldwide contributor of Greenhouse Gas Emissions (GHGs). In 2010 it contributed 35% of total GHGs (Bruckner et al., 2014). Within the energy sector, electricity is the end-use of energy consumption with the greatest utilization occurring in the most recent years (Bruckner et al., 2014). Together with renewable sources of energy, uranium has been argued as an alternative cleaner source of energy (IPCC, 2014). While it produces a range of hazardous contaminants that require rigorous procedures for containment, it is nevertheless a lesser GHG pollutant compared with other sources (e.g. coal). For example, lifecycle emissions of nuclear power are 29 tonnes CO_2e/GWh compared to 888 tonnes CO_2e/GWh for coal (WNA, 2011). In light of this, worldwide demand for uranium is expected to increase in the future, from 82,000 tonnes in 2017 to 89,600 tonnes in 2019 (NEA and IAEA, 2016; AG, 2017). While Australian exports are expected to decrease by 1.3% during FY 2017–2018 (due to a temporary halt in production at Olympic Dam mine), by FY 2018–2019 an increase of 1.6% is projected (AG, 2017).

Australia has 34% of worldwide uranium resources recoverable at a cost of less than US$130 per kilogram, which is about 1,287,000 tonnes (ASNO, 2017). At the present time (2018) there are three operating uranium mines Ranger Mine (owned by Energy Resources of Australia – ERA), Olympic Dam (owned by BHP Billiton) and the Four Mile Mine (Beverley Mine) (WNA, 2017). Together, the Ranger Mine and Olympic Dam Mine represent more than 80% of the domestic Australian uranium oxide output in the years 2013–2016, and supply 12% of the global demand (WNA, 2017). Their locations are presented in Fig. 1.

The operational profitability of the two main uranium mines (Ranger Mine and Olympic Dam) in Australia have previously been affected by spot price, production costs and market fluctuations as well as by climate conditions and extreme weather events (more details at Pizarro et al., 2017). For example, extreme weather events such as heavy storms, heavy flooding, and cyclones have had significant operational and economic repercussions for Ranger Mine. A review of the company operation reports over 10 years (2006–2016) allowed the identification climate impacts, which are summarised below.

- Mining and the processing plant were halted frequently (ERA, 2007a; ERA, 2008a; ERA, 2011; ERA, 2012).
- Operational pit was flooded several times, this prevented access (total or partially) to the high-grade ore (ERA, 2007a; ERA, 2008a; ERA, 2009; ERA, 2010; ERA, 2011; ERA, 2012).
- Tailing storage facilities and/or Pond Water were also flooded (ERA, 2007a; ERA, 2010; ERA, 2011; ERA, 2012).
- The main road access to the mine (Arnhem highway) was closed for most March 2007 (ERA, 2008a).

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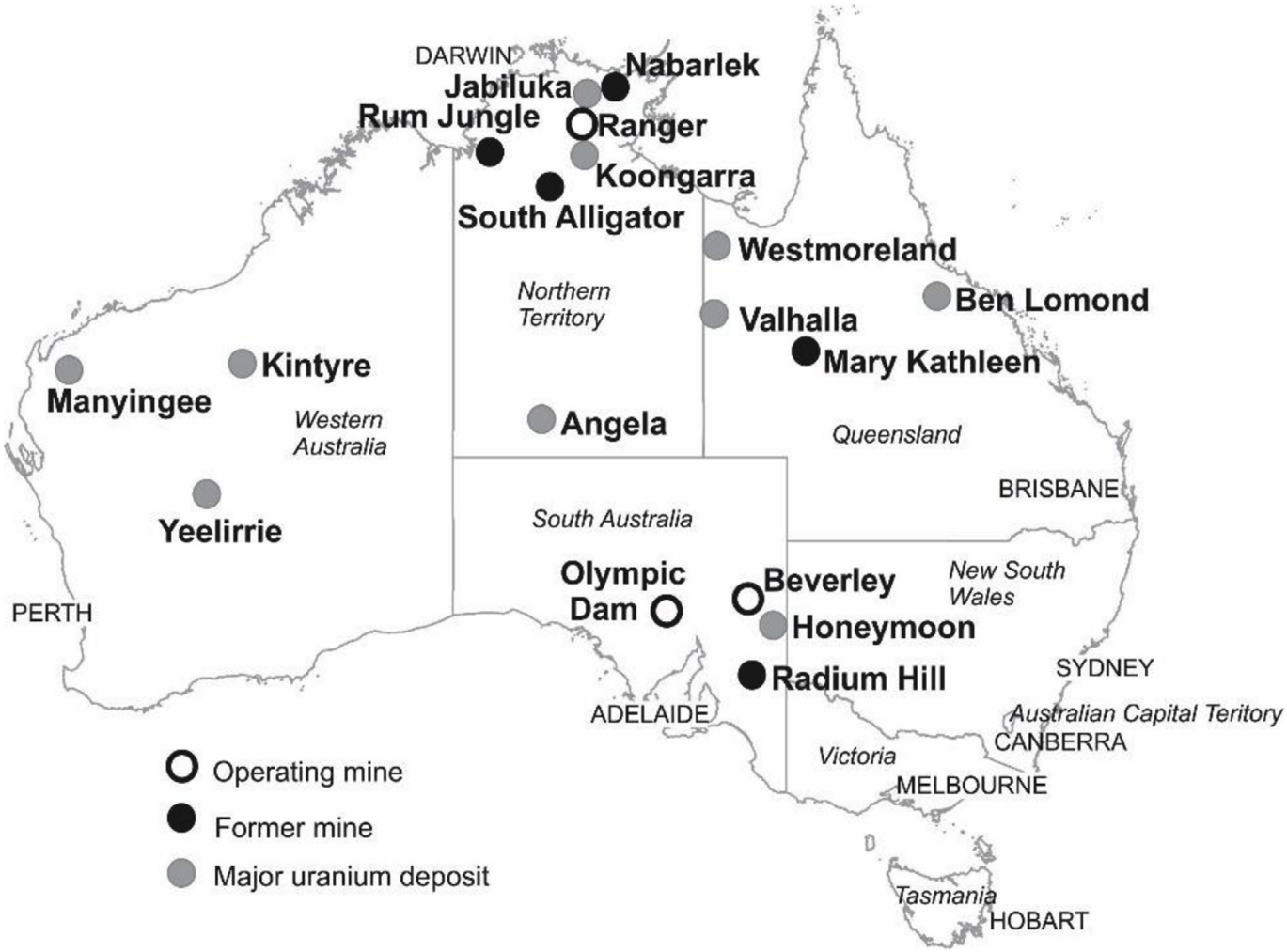

Fig. 1. Location of Ranger mine and Olympic Dam in addition to uranium deposits and former uranium mines (Source: after Australian uranium, 2017).

- Interruptions in power and water services in 2015.

The impacts on the Ranger Mine were associated with loss of production, which led to the need to purchase the mineral elsewhere (at higher costs and increased capital expenditure) in the market to fulfil contract obligations. All in all, this represented an estimated economic loss of A$934.5 million in the 2006–2016 period. It was clear that climate conditions and the extreme weather events also affect the supply chain and the external group of stakeholders. To study in depth how they have been affected and how they likely will be affected in the future, a vulnerability assessment (based on the concept of vulnerability employed by IPCC, 2001–2007, summarised by Jurgilevich et al., 2017) has previously been performed. The vulnerability assessment characterises the parameters of vulnerability (exposure, sensitivity and adaptive capacity) at each of the mines. This has been completed through a study of supply chain participant responses for each of the mines. This assessment has used the "lessons learned" from past extreme weather events to estimate future vulnerability.

2. Summary of climate projections in mine locations

A simplified review of the historical climate conditions at each the Ranger and Olympic Dam Mines along with climate projections are presented below. Four Representative Concentration Pathways (RCPs) have been considered in this research that include RCP2.6 (Van Veurren et al., 2011; Jubb et al., 2016), RCP4.5 (Van Veurren et al., 2011), RCP6 (Hijioaka et al., 2008), and RCP8.5 (Riahi et al.,2007).

Due to the uncertainties in the climate projections, the IPCC (2007) developed confidence criteria to qualify the level of certainty of each of the projections. Qualifiers such as '*very high*', '*high*', '*medium*', '*low*' and '*very low*' for each of the RCPs have been defined. The same confidence criteria have been used herein.

2.1. Ranger mine location and climate

The Ranger Mine is located 251.5 km east of Darwin in the Northern Territory. The closest meteorological station to the mine is the Jabiru Airport Station, located 2.7 km away.

In the Darwin region there are three seasons that include a wet season, cyclone season and a dry season (BOM, 2016a; Moise et al., 2015). The mean temperatures in this region have increased between 1.0 °C in the north east and 0.9 °C in the north west, for the period 1910–2010 (Moise et al., 2015). A warming tendency is expected with *very high confidence* in the future including an increase in minimum and maximum temperatures (Moise et al., 2015). In each of the RCP scenarios, increased average rainfall is expected at this location.

Extreme high temperature events are expected to increase in magnitude, frequency and duration (Moise et al., 2015) with *very high confidence* in all RCPs (Moise et al., 2015). Heavy rainfall intensity is expected to increase with *high confidence*, since a warmer atmosphere (in a warmer climate) can retain more moisture (Sherwood et al., 2010). However, the magnitude of this change has been estimated with *low confidence* (Moise et al., 2015). Cyclone intensity is projected to increase with *medium confidence*, but decrease in frequency (Moise

et al., 2015). The duration of droughts is projected to increase mainly under RCP 8.5.

2.2. Olympic Dam location and climate

Olympic Dam is situated 15.3 km north of the town of Roxby Downs in South Australia. The closest meteorological station is located at the Olympic Dam Aerodrome 4.4 km from the mine.

Daytime maximum temperatures and overnight minimum temperatures have increased by 0.8 °C and 1.0 °C respectively since 1910 (Watterson et al., 2015). Temperatures are expected to continue to increase at this location, with *high confidence* (Watterson et al., 2015). Rainfall projections are highly variable, by 2030 the annual mean variation expected is ± 10% and by 2090 under RCP 8.5 it is expected to decrease 4% (Waterson et al., 2015). However, extremes related to rainfall are expected to increase in intensity with *high confidence,* but the magnitude of this change has been estimated with *low confidence* (Waterson et al., 2015).

Drought duration is projected to increase with *medium confidence*, however, the change in frequency and intensity has been estimated with *low confidence* under the RCP 8.5. Heat wave frequency, intensity and duration are also projected to increase with a very *high confidence* (Waterson et al., 2015).

3. Identification of the Australian uranium supply chain

The literature provides numerous definitions of a modern supply chain (La Londe and Masters, 1994; Mentzer et al., 2001; Noémi, 2012; Christopher, 2016). The definitions rely on the physical flow of products from the source (suppliers) to the sink (customer). However, what really provides a competitive advantage is information flow (Sherer, 2005; Walker et al., 2007). As a result of this, the approach adopted herein considers the customer as the demand driver (primary source of information) who then passes information to their suppliers (Sherer, 2005; Walker et al., 2007). This information driven approach was used for the identification of the uranium supply chain participants for each of the mines.

3.1. Stakeholders as supply chain participants

In this study, stakeholders have been identified as “people who are adversely or positively impacted by our operations (or) those who have an interest or those who have an influence on what we do” (BHP Billiton, 2009b).

A total of 18 groups of stakeholders for each mine (Olympic Dam and Ranger) have been identified based on historical analysis of company reports (Freeman, 2010), their rights or interests (Walker et al., 2007) (including ownership), as well as groups who can be affected or benefit from the activities of the mines (BHP Billiton, 2009b).

It is also important to note that stakeholders' participation and their interests in any supply chain are dynamic and their interests may overlap or be somewhat influenced e.g. a community member may also supply good and services to the mine. For this study, they have been identified based on information available during 2015–2017. The stakeholders identified were categorised after Walker et al. (2007) and Bessant et al. (2003).

Mining Group: each of the mines (Ranger and Olympic Dam) have been considered as the leading partner/co-ordinator in each of their supply chains.

Downstream Group: included suppliers, contractors, consultants, and service providers.

External Group: included local community, independent individuals or groups who feel affected by the project, research teams, and invisible stakeholders (e.g. family support network) involved in the delivery project.

Upstream Group: paying customers and end users. These stakeholders were not considered in this study due to a lack of participants responding the survey.

4. Vulnerability assessment methodology

Climate vulnerability has been considered a function of exposure, sensitivity and adaptive capacity to climate change (Smit and Wandel, 2006; Füssel and Klein, 2006; Füssel, 2007; Pearce et al., 2009; Ford et al., 2010), which is the approach used by the IPCC 2001–2007. The same conceptual framework for vulnerability assessment that was applied to the Canadian mining industry developed by Pearce et al. (2009) has been used in this research. This assessment required input from stakeholders which has been collected via survey methods.

4.1. Survey

The survey was designed taking into account similar research in the mining field (Pearce et al., 2009; Ford et al., 2010). A total of twenty-five questions were prepared (see Annexe A), under five sections: respondents' information, current and future vulnerability, current and future adaptive capacity. Exposure/sensitivity has been assessed through historical parameters such as climate event magnitude, frequency and impacts expected for future parameters based on the RCP scenarios (summarised in Section 2). Scarcity or consumption of resources (e.g. water, energy) and factors that increase vulnerability (e.g. labour market) were considered to estimate the future vulnerability at each of the sites. Adaptive capacity was considered through (a) the evaluation of Risk Management Plans (RMP) and (b) their ability to deal with climate risks both in a reactive and proactive manner, (c) the existence of a vulnerability assessment or a Risk Reduction Plan (d) effectiveness of the current RMP to respond to climate change.

A total of 350 persons were contacted to participate in this study and 26 responses were obtained. It should be noted that some participants such as NGO and Services providers belong to both chains. The survey was delivered electronically between February and October of 2016.

4.2. Respondents profile

For the Mining and Downstream groups relevant persons with at least 5 years of experience were identified. In addition, the roles preferred were managers and professional since these individuals were considered the most qualified to provide valuable and reliable input to the study (Delbecq et al., 1975; Hsu and Sandford, 2007). In the case of the External Group, the search for relevant persons focused on the service-towns for each mine: Jabiru and Roxby Downs. A summary of the respondents is presented in Table 1.

4.3. Data analysis

The survey data was analysed using the IBM SPSS statistical software (V.22). Fisher's exact test was used to process data for questions containing categorical data values (e.g. types of climate risks, impacts of climate risks or flowed-through impacts), jointly with cross tabulations between the past and future cases. For questions with ordinal data (e.g. rate of exposure or flow-on impacts), the Kruskal-Wallis test was applied. When analysing the data for these tests, values of $p < 0.05$ indicate a significant difference in the distribution of responses between the groups considered (with respect to the rest of the sample). Values of $p > 0.05$ indicate the absence of a significant variation of responses between the groups of participants. Weighted averages of rankings and ratings were used to interpret the responses when the Kruskal-Wallis test did not provide any significant result. A summary of the survey results is provided below.

Table 1
Respondents of the survey.

a) Supply chain and External group of stakeholders Ranger Mine		b) Supply chain and External group of stakeholders of Olympic Dam mine	
Mining Group		**Mining Group**	
Management	1	Management	1
Scientist	1	Management	1
Total	2	Internal maintenance	1
Downstream group		Engineer	1
Mining services	1	Total	4
Consultant	1	**Downstream group**	
Contractor	1	Contractor-Transport	1
Total	3	Contractor	1
External group		Contractor-Electrical	1
NGO	1	Consultant-Environmental	2
Community services-education	1	Consultant-Project management	1
Researcher-Mining	1	Consultant-Technical services	1
Researcher-Animal welfare	1	Mining services	1
State Government-Mines and Energy	1	Total	8
Local Government	1	**External group**	
	6	Community member-	1
		State Government	1
		Community services-Local business	1
		Community Services-Education	1
		NGO	1
		Total	5

5. Results

5.1. Consideration of current climate risks

Respondents perceptions of their organisation's current vulnerability to climate events (based on their own experience) was analysed to provide a historical account.

5.1.1. Ranger Mine

The Mining and Downstream groups at the Ranger Mine considered intense rainfall and flooding as the most influential climate events to affect their organisation at the present time, with 100% of respondents in these groups selecting this option. This result is consistent with the data gathered from company reports before conducting the survey. E.g. The supply chain of the Ranger Mine has previously been affected by intense rainfall and flooding. The most serious impacts occurred during 2011 when mining operations were interrupted by flooding for almost five months (ERA, 2012). This event impacted production, decreasing it by 30%, and forced the company to purchase 2126 tonnes of uranium at an estimated cost of AU$253.2 million to meet contract commitments (Pizarro et al., 2017).

The External group members most frequently selected storms (66.7%), heat waves, (50.0%) and intense rainfall/flooding (40%) as the most influential climate events. Members of the External group mentioned storms with a higher tendency ($p = 0.028$) than members of the other groups in this chain. This may be a result of a reduced capacity to deal with excess water from storms due to their smaller size (compared to the mine), dispersed nature and/or reliance on community infrastructure to complete their business (e.g. roads).

5.1.2. Olympic Dam

The Mining group considered intense rainfall and heat waves (both 75%) and storms (50%) to be the most influential climate events at Olympic Dam. The Downstream group selected intense rainfall/flooding (75%), followed by droughts (37.5%) and heat waves (25%). The External group considered heat waves (80%) to have been the most influential climate event, followed by droughts (40%).

Some differences in responses were detected in this chain. For example, members of the Downstream group did not select storms as a significant climate event ($p = 0.048$) unlike other groups of the supply chain. Further, members of the External group did not consider intense rainfall/flooding to have been a relevant climate event, in contrast to other groups in the survey ($p = 0.040$) (Annexe A).

Minimal published information associated with the impact of extreme weather events at the Olympic Dam Mine is available. However, BHP Billiton has previously documented that their Olympic Dam mining activities have been adversely affected by weather events (BHP Billiton, 2015). These events have been characterised by variations in water supply and increasing temperatures (BHP Billiton, 2015) that have included extended periods of droughts e.g. the millennium drought and intense rainfall, storms and strong winds (Heavy storm in 2016). These events have caused the temporary closure of the surroundings roads to the mine (Arid Recovery, 2011) impacting the supply chain.

The variation in responses by the participants of the Olympic Dam supply chain seem to support the varied nature and duration of extreme weather events that have occurred and their impact on individual operations.

5.1.3. Discussion

The Mining Group members of both supply chains identified that intense rainfall/flooding is the most influential climate risk that they face, despite the location of both mines being in very different climatic zones – Ranger being tropical and Olympic Dam being arid.

The results of Olympic Dam's supply chain assessment suggest that in arid climates, extreme weather events, such as intense rainfall/flooding have a strong impact on supply chain member's ability to (a) cope with the immediate inundation and (b) project ongoing water reserves for operational activities (e.g. processing). At the Ranger Mine, intense rainfall/flooding results in significant financial impacts due to increased operational cost (pumping) and increased capital costs (increasing the height of tailings storage dams).

On the other hand, heat waves and droughts are common extremes in areas of arid climate (RDA, 2016), particularly relevant for Olympic Dam because of its location in an arid zone, the competitors (e.g. agriculture) for the use of this resource and the future projection of drought duration (section 2.2). Specifically, the mine's location has experienced heat waves, on average, of 94 days per year in the last 30 years, with temperatures over 35 °C (Watterson et al., 2015).

At either operations, heat waves are perceived to be a health issue by the local government and regulators organisations (Hodgkinson et al., 2014; Xiang, 2014; SafeWork SA, 2015). Increased potential for duration and severity of these events, may affect operation production and/or global supply; unless a transition to automation can be made.

5.1.4. Frequency of climate risks

The members of each supply chain estimated different frequencies of climate risks that they had been exposed to. Members of the Ranger Mine supply chain reported a frequency between “twice a year” to “once every 10 years” but the majority (36.4%) agreed on “once every 3 years”. Members of the Olympic Dam supply chain estimated a risk frequency that varied from “three or more times a year” to “less than

once climate event in 20 years". However, the majority (23.5%) of the members selected "three or more times a year".

This is a significant frequency of climate-related events at both locations that must be impacting financial performance. Pizarro et al. (2017) has previously shown that in each of the years, 2007, 2008, 2010, 2011 and 2012, increased capital expenditure at the Ranger Mine can be attributed to costs associated with the impacts of floods and cyclones. Heavy rainfall and cyclone activity intensity are expected to increase with *high confidence* at the Ranger Mine in the future. Heat waves frequency, intensity, and duration are projected to increase with a very *high confidence* at Olympic Dam, increasing the severity of dry climate conditions in the area. As a result of these projections, increased financial impact can be expected that may jeopardise production at these operations and global supply.

5.2. Specific climate impacts at the mine site (present and future)

Mining group respondents of both chains were asked about what aspects of the mining operation were currently (or have been historically) impacted by climate related conditions. The most commonly selected aspects were tailings/waste management facilities (63.6%) and transport within the mine site (54.5%). Ore extraction, processing, and maintenance activities were also identified as having been impacted (45.5%), in contrast with transport outside the mine site (36.4%) and mine planning (9.1%).

A comparison of the historical to the future expectations is not possible due to a lack of survey responses, however, the results can be discussed in isolation. With this in mind, tailings/waste management facilities were most commonly selected as being affected by respondents of the Mining group (66.7%), followed by processing (44.4%), transport within and outside the mine site (44.4%), and ore extraction (33.0%). Respondents were least likely to select maintenance activities (20.0%) and mine planning (11.0%) as being affected in the future. Although there appears to be a difference in both cases (current and future), this may be attributed to the unanswered questions. Nevertheless, it can be concluded that at each of the mine locations these climate related impacts will continue to affect operational output.

5.3. Exposure (present and future)

Members of each mining supply chain (for Ranger and Olympic Dam) were asked to rate their exposure to the climate risks that they had previously experienced. Respondents were asked to consider several climate risks and estimate their future exposure on a rating scale from 1 (least exposed) to 10 (most exposed).

5.3.1. Ranger Mine

The survey results for the Ranger Mine associated with the rating of exposure to climate risks (current and future) are provided in Table 2.

Overall, the members of the Ranger Mine supply chain considered that they are currently are, and expect to become, more exposed to climate-related risks in the future. The greatest risks were considered rainfall/flooding, storms, and heat waves. According to the results shown in Table 2, the Mining group is the most exposed in the present case while in the future it would be the Downstream group.

In the Present, the Mining group had a higher tendency towards rating intense rainfall/flooding the risk than other groups of the chain (Asymp. Sig. = 0.029). This is because they have directly faced economic and operational impacts in the past due to climate events (ERA, 2007a; ERA, 2011; ERA, 2012; Pizarro et al., 2017). Based on climate projections outlined in Section 2, it is obvious that the mine will be increasingly more exposed (as identified by survey participants) to rainfall/flooding events in the future which may potentially affect operational output and global supply.

5.3.2. Olympic Dam

Results of the average rating of exposure (current and future) across the Olympic Dam supply chain are presented in Table 3. A qualitative scale of 1 (least exposed) to 10 (most exposed) was provided to the respondents to allow an estimation of present and future exposure considering climate change.

According to the evaluation of respondents, the External group is the most exposed at the present time and Mining group are expected to be the most exposed in the future. The Mining group showed the greatest concern to future climate risks in this study. This coincides with the report by BHP Billiton (2015). The Mining group considered that they are less exposed to droughts (and related fires) than the other two groups, which reflects their confidence in their water management program. The ongoing management of water for the mine will be the main issue to ensure operability since drought conditions are expected to increase at this location in the future (See section 2.2).

5.4. Sensitivity (present and future)

Information was compiled about the general impacts that members of the supply chain have faced due to climate change and how they expect these risks to change in future.

5.4.1. Ranger Mine

Results of a sensitivity (present and future) across the Ranger Mine supply chain are presented in Table 4. A comparison between current versus future results is presented.

These results have revealed that the Mining group is the most likely affected by climate risks at the present as well as in the future. Differences between the group responses were detected. For example, in the current case, loss of revenue was not considered a relevant impact ($p = 0.015$) by members of the External group (compared to the other participants). Furthermore, the health and safety of workers was not considered relevant ($p = 0.042$) in the future by members of the Downstream group. Perhaps unsurprisingly, financial performance ($p = 0.031$) together with the loss of revenue ($p = 0.012$) at the mine were not identified as being important to members of the External group. The members of this group are more concerned about the environmental or community damage related to uranium mining operations than they are about economic/operational issues related to climate change as also ECNT (2014) suggested.

5.4.2. Discussion

In this chain, the members of Mining group reported the greatest sensitivity to climate conditions in the past. They also estimated that they would be one of the most sensitive groups to climate change in the future. This result is consistent with the climate projection in the area since heavy rainfall is expected to increase in all RCPs considered. Furthermore, cyclone activity is expected to increase in intensity with *high confidence*. In fact, this group has been severely affected in the past by floods in the operational pit, floods in the Tailings Storage Facilities (TSF), leading to a halt of operations. As a result, planned production has decreased and the financial performance has been affected (ERA, 2007a; ERA, 2011; ERA, 2012; Pizarro et al., 2017). However, this group has undertaken adaptation measures such as the commission of a brine concentrator (value at AU$220 million) to improve its water management capability in the wet season.

Downstream group members' responses indicated that they expected the health and safety of workers in the future to be less sensitive than the other groups. This suggests that this group might implement adaptation measures for protecting workers under future climate change such as heat stress training programs. These training programs are expected to ensure operations can continue during climate change.

5.4.3. Olympic Dam

Results of the sensitivity (present and future) across the Olympic

Table 2
Rating of exposure (present and future) across the supply chain of Ranger mine (qualitative scale of 1 (least exposed) to 10 (most exposed)).

Average rating of exposure	Present n = 11					Future n = 11		
	Mining (n = 2)			Downstream (n = 3)	External (n = 6)	Mining (n = 2)	Downstream (n = 3)	External (n = 5)
	Average*	x2 (df = 1)#	Asymp. Sig.**	Average*	Average*	Average*	Average*	Average*
Droughts	1.5	0.357	0.55	2.5	2	2	4	3.4
Fires	4.5	0.627	0.428	2.5	2.83	5.5	4	2.75
Heat Waves	4.5	0.004	0.949	3	3.83	5.5	4	4.6
Storms	8	3.22	0.073	5	5.17	7.5	7	4.8
Intense rainfall/flooding	**9.5**	**4.746**	**0.029**	6	4.67	9.5	7.67	4.6
Average score	5.5			4.25	3.33	5.75	5.83	4

*1: least exposed, to 10: most exposed.
#x2 (df = 1): Values of the Chi Square Distribution of the Kruskall Wallis Test with 1 degree of freedom.
**Asymp. Sig. = Asymptotic significance.
Values of Asymptotic Significance at or lower than 0.05 are highlighted in bold. This means the difference between the mean rating of exposure between the group of analysis and the rest of the sample is significantly different with a 5% confidence level.

Table 3
Average rating of exposure (present and future) across the supply chain of Olympic Dam mine (qualitative scale of 1 (least exposed) to 10 (most exposed)).

Average rating of exposure*	Present			Future		
	Mining	Downstream	External	Mining	Downstream	External
	(n = 3)	(n = 8)	(n = 5)	(n = 4)	(n = 8)	(n = 6)
Droughts	1	3.5	4.2	3	4.43	4.4
Fires	1	3.25	4.2	1.67	5	4.6
Heat Waves	6.33	3.4	5.75	6.5	5.57	6
Storms	5	4.5	3.5	7.67	6.17	4.6
Intense rainfall/Flooding	4.67	4.75	3.2	8.33	6.75	4.6
Average score	3.6	3.88	4.17	5.67	5.59	4.84

*1: least exposed, to 10: most exposed.

Dam supply chain are presented in Table 5.

The same sequence-rank of groups is repeated in this chain. The Mining group is estimated as the most affected by climate risks in the present and in the future, followed by the Downstream and the External groups. The Mining group considered several items as having been impacted (75%) by climate risks (see Table 5). Regarding the expected future impacts, members of the Mining group agreed that greater climate risks would lead to "increased costs" (100%). They estimate future impacts will be the same as those experienced at present, apart from the supply of essential inputs or services (25% vs 50%) and transportation of product (0% vs 25%).

Operational disruption (87.5%) was the most popular selection in the present by The Downstream group followed by increased costs and supply of essential inputs (62.5%). They reported a varied of increasing tendency towards estimating future likely climate risks, for example, the "quality of production" (impacts on their ability to follow their usual quality-controlled procedures) was considered to be affected in the future (See Table 5). This might be directly related to the water scarcity and droughts which are projected to increase in duration (section 2.2) at the location.

Table 4
Climate impacts reported across the Ranger mine supply chain.

Climate impacts	Present				Future				
	Mining	Downstream	External		Mining	Downstream		External	
	n = 2	n = 3	n = 5	p value	n = 2	n = 3	p value	n = 6	p value
Financial performance	100.00%	66.70%	0.00%	0.057	100.00%	100.00%	0.141	0.00%	**0.031**
Loss of revenue	100.00%	100.00%	0.00%	**0.015**	100.00%	100.00%	0.225	0.00%	**0.012**
Increased costs	100.00%	66.70%	20.00%	0.136	100.00%	66.70%	0.664	75.00%	0.672
Operational disruption	100.00%	100.00%	60.00%	0.436	100.00%	66.70%	0.521	100.00%	0.365
Delayed production	100.00%	100.00%	20.00%	0.245	100.00%	66.70%	0.5	25.00%	0.295
Quality of production	50.00%	33.30%	0.00%	0.496	50.00%	0.00%	0.761	0.00%	0.688
Supply of essential inputs or services	50.00%	66.70%	0.00%	0.057	50.00%	66.70%	0.371	25.00%	0.437
Transportation of product	50.00%	66.70%	20.00%	0.657	50.00%	33.30%	0.664	0.00%	0.224
Health and safety of workers	50.00%	33.30%	60.00%	0.622	50.00%	0.00%	**0.042**	75.00%	0.514
Infrastructure/plant & equipment damage	50.00%	33.30%	40.00%	0.699	100.00%	33.30%	0.565	50.00%	0.637
Average	75.00%	66.70%	22.00%		80.00%	53.30%		35.00%	

Values of Asymptotic Significance at or lower than 0.05 are highlighted in bold. This means the difference between the mean rating of exposure between the group of analysis and the rest of the sample is significantly different with a 5% confidence level.

Table 5
Climate impacts reported across the Olympic Dam mine supply chain.

Climate impacts	Present				Future			
	Mining	Downstream	External		Mining	Downstream	External	
	n = 4	n = 8	n = 5	p value	n = 4	n = 8	n = 4	p value
Financial performance	75.0%	50.0%	0.0%	0.057	75.0%	75.0%	0.0%	**0.031**
Loss of revenue	75.0%	50.0%	40.0%	0.459	75.0%	87.5%	25.0%	0.13
Increased costs	50.0%	62.5%	40.0%	0.459	100.0%	62.5%	50.0%	0.328
Operational disruption	75.0%	87.5%	20.0%	**0.012**	75.0%	87.5%	50.0%	0.179
Delayed production	50.0%	50.0%	0.0%	**0.038**	50.0%	62.5%	25.0%	0.295
Quality of production	0.0%	0.0%	20.0%	0.504	0.0%	12.5%	0.0%	0.688
Supply of essential inputs or services	25.0%	62.5%	40.0%	0.699	50.0%	37.5%	50.0%	0.563
Transportation of product	0.0%	37.5%	0.0%	0.219	25.0%	50.0%	0.0%	0.224
Health and safety of workers	75.0%	37.5%	60.0%	0.622	75.0%	62.5%	75.0%	0.514
Infrastructure/& plant equipment damage	50.0%	25.0%	40.0%	0.699	50.0%	25.0%	50.0%	0.637
Average score	47.5%	46.3%	26.0%		57.5%	56.3%	32.5%	

Values of Asymptotic Significance at or lower than 0.05 are highlighted in bold. This means the difference between the mean rating of exposure between the group of analysis and the rest of the sample is significantly different with a 5% confidence level.

Members of the External group were most likely to select health and safety of workers (60%). In this group, climate-impacts are expected to increase for all cases mentioned except loss of revenue, which decreased from 40% to 25% in future.

Differences between group responses were detected e.g. in the current case, members of the External group do not estimate operational disruption ($p = 0.012$) and increased costs ($p = 0.038$) as relevant climate-related impacts compared with the other two groups. In addition, financial performance ($p = 0.031$) was considered to be only of future relevance by the External group.

5.4.4. Discussion

Almost all groups reported being sensitive to varying degrees of climate risks in most of the economic and operational impacts. This is particularly relevant if according to climate projections presented in section 2.2, the mean temperature, heat waves and rainfall are expected to increase in all RCPs.

The Mining group was the most sensitive to climate risks at present case. They estimated they would also be the most sensitive out of all the other groups in the future. This group showed more concern about the internal economic impacts such as financial performance, loss of revenue and increased cost in the present and future case compared with the other groups. In contrast, the results discussed by Pearce et al. (2009) indicated that uranium mining participants reported to have more concern about external market fluctuations than the internal impacts that can cause the climate change on mining. This included potential impacts to both ore extraction and surface equipment, but it should be noted that the climate in the Canadian uranium mining areas is different to that in Australian uranium mining areas.

The External group of this chain considered there to be lesser impact by climate risks at present than in future. They also showed lower concern over the financial performance and loss of revenue in the present and future case compared with the other two groups. This suggests that the members of this group (mainly community, NGOs and Government representatives) are not concerned about the economic issues related to climate risks, however, they consider health and safety of workers to experience the greatest climate-related in the future.

5.5. Indirect flow-through and flow-on impacts

In order to gather information about indirect climate impacts faced by supply chain members and external stakeholders, respondents were asked about the 'flow-through' and 'flow-on' effects of climate impacts from other organisations. This allowed the identification of which organisations have historically affected their own organisation. In turn, they were likewise asked to identify, under current climate conditions, what organisations might be affected by 'flow-on' climate events from their own organisation. For this, respondents ranked the alternatives using the scale from 1 = most affected to 8 = least affected. The results for each of the chains is presented below.

5.5.1. Ranger Mine

Based on the sum of responses that were "not applicable", "other" and/or "skipped" (45.2%) it was difficult to sort the responses for this chain in a meaningful way. Nevertheless, it was determined that respondents were least likely to select that a Mining company (9.1%) would produce 'flow-through' impacts onto their own organisation under the current climate conditions. Regarding the future conditions, respondents were most likely to select the local community (54.6%) as indirectly affecting their own organisation through climate related risks, followed by Utility companies and the Mining company (both 36.4%). Mining services (27.3%) and Transport companies (18.2%) were least identified as likely to produce flow-through impacts affecting one's own organisation in a future climate event.

The Mining group has been identified as the most affected by flow-on impacts (3.92), followed by the Downstream group. No significant differences between groups were detected in this question. The Ranger Mine has been affected by flow-on impacts in the past, such as flooding of the Arnhem Highway (ERA, 2007a; ERA, 2013c), the Jabiru township (ERA, 2007b) and its surrounding roads throughout Kakadu National Park (ERA, 2008b).

5.5.2. Olympic Dam

External respondents estimated that the most indirect (flow-through) risk affecting their own organisation would be the mining company (70.1%) and the local community (52.9%) in the future. Other members of the chain considered their own organisation likely to be affected in the future by transport and utility companies, and mining services, all reporting 41.2%.

The Mining services group was identified as the least affected by flow-through impacts in both the present and future cases. Furthermore, the Mining Company was found to be the most affected by flow-through impacts in the future. This was similarly indicated by Hodgkinson et al. (2014) where participants of the mining supply chain identified climate impacts on mining infrastructure, transport (ports), and energy (electricity outages). In 2016 Olympic Dam was affected directly and indirectly by a severe storm (extreme rainfall, strong wind, and lighting) (BOM, 2016b), which caused a widespread blackout

across the state of South Australia. This storm forced the shutdown of the mine for 15 days and resulted in an economic loss for the mining company of AU$137 million (BHP Billiton, 2017).

The Downstream group of the supply chain of Olympic Dam mine was considered as the most affected (3.03) by flow-on impacts within the chain followed by External group (5.17). Mining services (engineering companies, consulting companies or maintenance companies) belonging to Downstream group have been affected by the increased cost of safety shutdown of critical elements of the mine site, and extra working hours for personnel, when Olympic Dam mine stopped its operations after the severe storm of September 2016 (Burns et al., 2016).

Based on the survey results, only one difference in responses between groups was detected to this question. Members of the External group ranked manufacturing as being most likely to be affected (Asymp. Sig. = 0.046) by flow-on impacts from their own organisation.

5.6. Factors that can increase future vulnerability

The survey results have revealed that there is concern associated with increasing vulnerability of a range of factors in both of the mine supply chains. These factors include: the age and design of assets, geographical location, type of operation, the frequency of climate events, intensity and magnitude of the events, and impact on labour force availability.

5.6.1. Ranger Mine

The respondents of the three groups within the Ranger Mine's supply chain indicated that geographical location and frequency of climate events were the major factors likely to increase their vulnerability to future climate risk. This is important since both factors cannot to be controlled. For this mine, the design or age of assets was not considered as particularly relevant factors by any group. This may be a result of significant capital investment in the recent years. Some adaptation measures to modify assets have been performed, mainly by the Mining group, including a rise (three times) of the wall of the tailings storage facility, construction of a brine concentrator, and additional pond water storage capacity (ERA, 2012).

5.6.2. Olympic Dam

All of the Olympic Dam supply chain groups identified the frequency of climate events and impact on labour force availability as having the most future vulnerability. Labour force availability can be indirectly affected by an impact of climate change e.g. water scarcity or power outages at the mine site may lead local communities relocating which could cause a deficit in the labour force (Hodgkinson et al., 2010). The design of assets was relevant for members of the Mining group only since this group has already considered the impact of climate change on their infrastructure. For example, the expansion project of Olympic Dam mine considered measures such as additional freeboard in the TSF, levees, and the sea walls in the port facility (BHP Billiton, 2009a).

5.7. Increase of resources required in light of climate change

Respondents were asked to indicate any increase in resources they might expect in the future in response to climate change. Resources were clarified as being water, energy, inputs (materials and equipment), labour, infrastructure, technology, and knowledge and expertise.

5.7.1. Ranger Mine

The Mining group of this chain most frequently indicated that their energy needs would increase (100%), followed by labour, technology, and knowledge/expertise (50% each). In the Downstream group, the most popular resources nominated were water, energy, infrastructure, technology and knowledge/expertise. However, it was not possible to sort these into a descending order as they were all selected an equal number of times (50%). The External group (e.g. community) most commonly selected energy (40%) as the resource most likely to increase in the future as a result of climate change. This may be directly attributed to their personal knowledge of how energy plays an important role in their own lives. E.g. electricity for lighting, cooling; fuel for transportation, heating, and cooking. None of the groups indicated that the demand of Inputs (materials and equipment) would be expected to increase in the future.

5.7.2. Discussion

All the members of the chain agreed that energy is the most likely resource required in the future to increase. However, based on ERA (2013b) there was no forecast variation in energy consumption even when the underground mine expansion was considered. It is expected in this case that Rio Tinto (2016) has committed to energy-efficiency measures e.g. trials of new technology to its operations (Rio Tinto, 2014, 2016). Furthermore, as part of the increasing need for knowledge/expertise and understanding about climate change, the Australian Government has prepared adaptation/strategy plans for the surrounding region such as Kakadu National Park (AG, 2010) and the local government has undertaken adaptation plans (2010–2020) for the local community (WASC, 2010).

5.7.3. Olympic Dam

All members of the Olympic Dam supply chain agreed that the need for water, energy, labour, and knowledge/expertise resources may increase in the future. In addition to these, the Downstream group members also considered that improved infrastructure would be required. Overall, members of both supply chains estimated an increase in demand of almost all resources in the future. Similar to the Ranger Mine results, a potential increase in Inputs (including materials and equipment) was dismissed by all respondents.

5.7.4. Discussion

Water scarcity can impact the productivity of a mine, especially in the case of Olympic Dam where there is little surface water in close proximity to the operations. Considering the mean annual rainfall is expected to decrease in the future at this location, this could have a significant impact on the operations. Both the mine and nearby towns (Roxby Downs, and Andamooka) rely on groundwater extracted from the Great Artesian Basin (Torrisi and Trotta, 2009). Olympic Dam has implemented a plan for sustainable water use, which includes a water efficiency program to reduce water demand (Torrisi and Trotta, 2009). In addition, the local community has been advised on water saving and water sustainability (Roxby Downs Council, 2014).

The most commonly occurring extreme weather event at the mine's location is heat waves during the summer, resulting in an increase (by almost 70%) in electricity consumption (Pilli-Sihvola et al., 2010; ESAA, 2015). Heat waves are expected to increase in frequency, intensity and duration in this area (Watterson et al., 2015) leading to higher electricity consumption as cooling becomes a priority. Olympic Dam is the largest single client of Electranet (the distribution company in South Australia). Olympic Dam's annual electricity consumption is about 7% of the total electricity consumption in South Australia (BHP, 2009c), having a significant impact on the increase in electricity demand during a heat wave.

Energy and water resource supplies may be affected by extreme weather events in the future, and subsequently, the mine's operations since uranium mining is an energy and water intensive operation (Schneider et al., 2013). The survey's results confirm the concern for these two resources (water and energy) that may become stressed in the future as a result of climate change and affect the ability to maintain sustainable uranium mines.

Table 6
Evaluation of the Risk Management Plan across the supply chain of Ranger mine based on a qualitative scale of 1 (poor) to 10 (excellent).

Evaluation of the Risk Management Plan (RMP). Scale of 1 (poor) to 10 (excellent)	Mining (n = 2)			Downstream (n = 2)	External (n = 4)
	Average*	x2 (df = 1)#	Asymp. Sig.**	Average*	Average*
How well identified are the key climate-related risks in the Risk Management Plan (RMP)?	5	0.85	0.36	6.5	7
How relevant/specific is the RMP to the actual site or operation?	8	0.33	0.56	6.5	8
How adequate are the current risk mitigation procedures and response/contingency plans?	8.5	0.6	0.44	7.00	7.25
How clear are the different positions, roles and responsibilities of the personnel required to respond to the event?	9	1.28	0.26	6.5	8
How clear are the guidelines and procedures to follow in the case of a climate event?	9	0.67	0.41	6	7.75
How well is the RMP communicated to staff?	6.5	0.28	0.6	7	7.25
How regularly is the RMP updated?	7.5	0.12	0.73	7.5	7.5
How effective is the communication between the other companies/organisations related with your company e.g. Energy, Water, and Transport, Communication Company or other?	3.5	**4.16**	**0.04**	5.5	7.75
Average score	7.17			6.56	7.56

*1 poor, to 10 excellent.
#x2 (df = 1): Values of the Chi Square Distribution of the Kruskall Wallis Test with 1 degree of freedom.
**Asymp. Sig. = Asymptotic significance.
Values of Asymptotic Significance at or lower than 0.05 are highlighted in bold. This means the difference between the mean rating of exposure between the group of analysis and the rest of the sample is significantly different with a 5% confidence level.

5.8. Current adaptive capacity

The current adaptive capacity of organisations was assessed by asking respondents to rate a range of items in their Risk Management Plan (RMP) with a qualitative scale from 0: low to 10: excellent. In addition, there were questions posed about their organisation's approach (proactive or reactive) to deal with climate risks (results expressed in percentages), whether a vulnerability assessment and a risk reduction plan had been undertaken, and the identification of opportunities from climate change.

5.8.1. Ranger Mine

The results of the evaluation of the RMP across the supply chain of the Ranger Mine are presented in Table 6.

According to these results, the External group gave the highest overall score (7.56) for their RMP, followed by the Mining (7.17) and Downstream (6.56) group. The effective communication between companies related was considered the weakest item in their RMPs by Mining (3.5) and Downstream (5.5) group. In the case of Mining group, ERA has undertaken stakeholder engagement programs for other purposes e.g. expansion plan to mine underground (ERA, 2013a), so the adaptive capacity to communicate with related companies exists - it just needs to be mobilised in this case.

Regarding to the approach to deal with climate-risks, members of the External group stated they have a proactive approach (83.3%), however no members of this group indicated their organisation had conducted a vulnerability assessment or had developed a risk reduction plan. Due to the high percentage of “unsure” responses in the previous questions (60.0% and 66.6% respectively), it may be inferred that there is a lack of knowledge about these two concepts. This group did not identify any opportunities that may arise from climate change for their business.

The Mining group identified that they have a proactive approach when dealing with climate risks (100%) and know about the vulnerability assessment (50%) and risk reduction plans in place (50%). However, similar to the External group, they did not identify any opportunities that may be derived from climate change. Further, members of the Downstream group reported to have mainly a proactive approach (66.66%) to deal with climate risks. However, 66.66% of respondents reported that they did not have a vulnerability assessment and a risk reduction plan within their operations.

5.8.2. Discussion

Taking into account the evaluation of the RMP, the approach to dealing with climate risks and the existence of a vulnerability assessment and a risk reduction plan, it seems that the Mining group of this chain is the best prepared to meet climate change challenges. The Downstream group appears to be the least prepared although the reason for this is not clear. This group consists mainly of contractors and consultants, and while they may be small organisations, they are required to comply with the same requirements in all aspects as the outsourcing companies as was stated by ERA (2007b). In addition, in 2005 ERA undertook a program to upgrade the contractor's management system, which included the assessment of critical risks (ERA, 2007b). The results of this research presented herein, suggest that compliance may have slipped in the decade since this program was undertaken.

5.8.3. Olympic Dam

The results of the evaluation of the Risk Management Plan across the supply chain of the Olympic Dam Mine are presented in Table 7.

The highest overall average rating for their RMP (7.84) was provided by the Mining group. They also gave the highest score for individual items identified in the question except for effective communication between related companies, which was the lowest score (the same response as Ranger Mine). Members of the External group gave an overall rating average of 7.19. Communication between companies was once again identified as with the lowest score (5.75) in this group. Downstream group gave the lowest overall rating (6.58) to their RMP and also the lowest rating for any single item of the plan, namely the relevance of the RMP to their situation (6.00).

Respondents of Mining group stated they had a mainly proactive approach (75%) for dealing with climate risks, they have performed a vulnerability assessment (50%), they have a risk reduction plan (50%) and they have identified potential opportunities from climate change (25%). Members of the External group reported a mainly reactive approach (60%) to dealing with climate change, with the highest percentage of “unsure” responses in the chain regarding the existence of a vulnerability assessment, risk reduction plan and identification of opportunities (60%, 80% and 60% respectively).

Members of the Downstream group reported having both a proactive and reactive approach (50% for each). They also provided a strongly negative response to the existence of a vulnerability assessment and a risk reduction plan (both 87.5%). They have not identified

Table 7
Evaluation of the Risk Management Plan across the supply chain of Olympic Dam mine based on a qualitative scale of 1 (poor) to 10 (excellent).

Evaluation of the Risk Management Plan (RMP). Scale of 1 (poor) to 10 (excellent)	Mining (n = 4)	Downstream (n = 8)			External (n = 4)
	Average*	Average*	x2 (df = 1)#	Asymp. Sig.**	Average*
How well identified are the key climate-related risks in the Risk Management Plan (RMP)?	7.75	5.88	1.21	0.27	7.33
How relevant/specific is the RMP to the actual site or operation?	8.5	**6**	**5.7**	**0.02**	8
How adequate are the current risk mitigation procedures and response/contingency plans?	8.25	7.13	0.27	0.6	7.25
How clear are the different positions, roles and responsibilities of the personnel required to respond to the event?	8.5	7.38	0.11	0.74	7.25
How clear are the guidelines and procedures to follow in the case of a climate event?	8.5	7.13	0.35	0.55	8
How well is the RMP communicated to staff?	7.75	7	0.08	0.78	7.33
How regularly is the RMP updated?	7.5	6.13	1.23	0.27	6.67
How effective is the communication between the other companies/organisations related with your company e.g. Energy, Water, and Transport, Communication Company or other?	6	6.63	0.34	0.56	5.75
Overall average rating	7.84	6.58			7.19

*1 poor, to 10 excellent.
#x2 (df = 1): Values of the Chi Square Distribution of the Kruskall Wallis Test with 1 degree of freedom.
**Asymp. Sig. = Asymptotic significance.
Values of Asymptotic Significance at or lower than 0.05 are highlighted in bold. This means the difference between the mean rating of exposure between the group of analysis and the rest of the sample is significantly different with a 5% confidence level.

operational opportunities from climate change. Further, members of Downstream group reported more concern (Asymp. Sig. = 0.02) about the relevancy of their RMP for the site of operation, explaining the lower rating compared to the other groups.

5.8.4. Discussion

Based on the previous results, it seems that the Mining group is the best prepared in this supply chain. This group gave a good rating for their RMP, they have mainly a proactive approach, they have knowledge about a vulnerability assessment and a risk reduction plan and they were the only group that identified opportunities that may arise from climate change although those opportunities were not specified. Some members of this group stated that “climate change is well understood” or “vulnerability assessment will be complete in 2016”.

In contrast, the Downstream group appears to be the worst prepared to face climate risks: this group gave the lowest overall score to their current RMP. Members of this group reported a high percentage of “no” answers to the questions relating to the existence of a vulnerability and risk reduction plan. This suggests there may be a lack of knowledge of these concepts driven by poor communication or there may be no plans. This is confirmed by direct comments from respondents such as “have not heard about this”. They were unsure in the identification of opportunities, which also supposed a lack of knowledge in this matter.

5.9. Future adaptive capacity

In order to estimate the current supply chain's future adaptive capacity, the respondents were asked to provide an overall rating of their RMP with respect to how well it would cope with greater future climate risks. The comparison between the current cases versus future is presented below.

5.9.1. Ranger Mine

Similar to the previous highest overall rating given by the Ranger Mine, External group members also gave the highest overall rating for the future adaptive capacity. However, the External group's rating of their RMPs for future conditions was lower than for current conditions (7.56 current versus 6.00 future). The Mining group also gave a lower score for their RMP for coping with future events than they did for current conditions (7.17 versus 5.50). This result is in contrast with the estimated by ERA (2012), where the company stated they are confident they will be able to manage future climate events.

The Downstream group again returned the lowest overall score (6.56 vs 4.33). Nevertheless, some members of this group, such as Ports or Rail, present a proactive approach to dealing with climate risks and climate change (Darwin Port Corporation, 2012; ARA, 2012).

5.9.2. Discussion

Based on the previous results, the External group of this supply chain might have the best RMP to face climate change. In fact, members of this group (e.g. Government organisations) have shown increased interest and concern to bring climate change concepts to all communities in an attempt to increase their adaptive capacity. Until a few years ago, indigenous communities showed a lack of, or unclear, knowledge about climate change (Petheram et al., 2010). More recently, programs administered by national and local government have provided climate change adaptation advice such as the climate change action plan NTG (2011), the Flood Mitigation Advisory Committee (NTG, 2015) or the Kakadu National Park: Climate change Strategy (AG, 2010) provided knowledge to communities.

5.9.3. Olympic Dam

For the Olympic Dam mine supply chain, the Mining group again returned the highest RMP score, even though the score given for handling future conditions was lower (current 7.84 vs future 7.00). This was followed by the Downstream group (current 6.58 vs future 6.38) and the External group returned the weakest RMP score for coping with future conditions (current 7.19 vs future 6.00). According to these results, the Mining group may be the best prepared for climate change followed by the Downstream group. In fact, members of Downstream group such as Ports have undertaken several measures to reduce the risks of climate change, including a vulnerability assessment for the region and the identification of adaptation measures such as AdaptWest (2015) and; AdaptWest (2016).

5.10. Changes needed to improve the adaptive capacity

5.10.1. Ranger Mine

The members of the Ranger Mine supply chain considered changes that might be needed to improve adaptive capacity. The results are provided in Table 8.

The Mining group were most likely to select operational procedures and technical changes as needed to improve adaptive capacity. The Downstream group selected operational procedures, technical changes,

Table 8
Changes posed across the supply chain of Ranger mine.

Changes posed in the question	Mining	Downstream	External	P Value
	n = 2	n = 3	n = 4	
Management procedures	50.00%	0.00%	75.00%	0.233
Administrative procedures	0.00%	0.00%	75.00%	**0.04**
Operational procedures*	100.00%	33.30%	100.00%	0.224
Work practices	0.00%	0.00%	75.00%	0.178
Technical changes	100.00%	33.30%	25.00%	0.672
Management approach/ leadership	50.00%	33.30%	25.00%	0.593
Not applicable	0.00%	33.30%	0.00%	0.563
Other (please specify)	0.00%	0.00%	0.00%	0.833
Average score	37.50%	16.70%	46.90%	

*Operational procedures include mechanical, extraction and processing operations of the mine, contractors and consultants in addition to those of local organisations procedures required to operate.
Values of Asymptotic Significance at or lower than 0.05 are highlighted in bold. This means the difference between the mean rating of exposure between the group of analysis and the rest of the sample is significantly different with a 5% confidence level.

and management approach with equal frequency (33.3%). The External group identified operational procedures with greatest frequency (100%), followed by management procedures, administrative procedures and work practices (all 75%). Further, members of the External group selected administrative procedures in a higher proportion ($p = 0.04$) than the other groups. They also enumerated the highest number of changes required to improve the future adaptive capacity.

5.10.2. Discussion

All members of this chain selected operational procedures as the most important change required to improve their adaptive capacity. Operational procedures include mechanical, extraction and processing operations of the mine, contractors and consultants in addition to those of local organisations procedures required to operate. It was suggested that this change can be achieved by modifying the current risk identification processes, considering the cumulative impact of climate risks over the infrastructure, implementing measures that address the risks identified, monitoring the risks and identifying measures to ensure they are suitable and developing local climate projections to evaluate potential risks as Mason and Giurco (2013) suggested. Further, Rio Tinto has recognised the value of integrating climate change factors into its business management and planning (C2ES, 2013), which can facilitate this operational change.

For members of the External group (mainly NGOs, Government organisations and communities) administrative and management procedures are a matter of concern if they do not change in the future. This is because administrative procedures can facilitate or impede adaptation to climate change (Productivity Commission, 2012; Hussey et al., 2013). In addition, local government has already discussed the high vulnerability to climate change and that it is important to adapt at all levels (government, business, communities and individuals) (WASC, 2010). As a result of this national, state and local government organisations have been preparing adaption plans and engagement activities with community members (e.g. BMT WBM, 2010; Darwin City Council, 2011).

5.10.3. Olympic Dam

The members of the Olympic Dam supply chain and the External group estimated that changes in all aspects posed in the question are required (in different percentages) as can be seen in Table 9. However, operational procedures were selected by the three groups with the highest percentage in each group.

Table 9
Changes mentioned across the supply chain of Olympic Dam mine.

Changes posed in the question	Mining	Downstream	External
	n = 4	n = 8	n = 4
Management procedures	50.00%	37.50%	50.00%
Administrative procedures	25.00%	25.00%	25.00%
Operational procedures*	75.00%	75.00%	50.00%
Work practices	75.00%	37.50%	25.00%
Technical changes	25.00%	12.50%	25.00%
Management approach/leadership	25.00%	37.50%	25.00%
Not applicable	0.00%	12.50%	25.00%
Other (please specify)	25.00%	0.00%	0.00%
Average	37.50%	29.70%	28.10%

*Operational procedures include mechanical, extraction and processing operations of the mine, contractors and consultants in addition to those of local organisations procedures required to operate.

5.10.4. Discussion

Some members of this chain have already taken action to trigger changes to their operational procedures. For example, BHP Billiton integrated climate change into its expansion planning process for the Olympic Dam mine (although expansion planning was postponed in 2012), including analysis of the climate projections for the project location and how they can affect the operational procedures and the physical impacts of the operations (BHP Billiton, 2009a; BHP Billiton, 2015). Furthermore, they have analysed and assessed how to increase the business resilience in response to climate change. Changes have been made to operational procedures (BHP Billiton, 2015) such as a sustainable water usage (Torrisi and Trotta, 2009), energy efficiency use, low emission technologies, and training (BHP Billiton, 2015). The local government of South Australia has prepared vulnerability assessment and adaptation planning reports, which included members of this supply chain such as Mining, Roxby Downs community, and Transport (Port Augusta, Roads and Railways) (Hodgkinson et al., 2014; RDA, 2016).

6. Conclusions

This research has analysed the vulnerability that the uranium supply chains in Australia have to climate change. This study has shown that both supply chains have the capacity to respond to current climate risks. However, the capacity to anticipate future climate risks, including a vulnerability assessment or risk reduction plan appears to be very limited. The vulnerability assessment revealed the different aspects of sensitivity (direct and indirect) to climate change in both supply chains with a special focus on the impacts on mining companies. It was shown that vulnerabilities are location-specific. The most vulnerable group for the future was identified as the Mining group in both chains. They were also identified with the greatest capacity to adapt. At both locations, the least prepared group is the Downstream group suggesting that these groups may require the most assistance to reduce their vulnerability.

Based on the RCP scenarios, it likely that in all scenarios that there should be an expected increase in rainfall intensity at the Ranger Mine and decrease in rainfall at Olympic Dam. Based on the results of the survey, it is evident that both of these locations have been impacted by severe storms and drought in the past resulting in increased operating costs and lost revenue. This study has revealed that the adaptive capacity across the uranium supply chain might require some changes at different levels (operational and administrative), especially in administrative procedures which are perceived as a constraint to be better prepared to face climate change. It was shown that the chains are strongly connected and weaknesses within any of the links can have flow-on impacts to others that may negatively impact the whole chain. It has been revealed that the communication between companies is the

weakest item within the Risk Management Plans and this is certainly an easy area to improve. There is a need for a more in-depth study to identify specific adaptation needs and options that can be implemented across the chains.

The requirement to identify and implement adaptation options at these locations (Ranger Mine and Olympic Dam) is imperative to secure the global uranium demand. With these mines currently supplying 12% of the world demand, and an expected increased potential in the future, the impacts of climate change on daily operations are required to be considered to avoid/revert to reliance on more polluting energy sources around the globe.

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Appendix A. Supplementary data

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